CHAPTER 2: GEOMORPHOLOGY, HYDROLOGY, AND HABITAT

Formation and maintenance of aquatic habitat necessary for the native fish community are controlled by the physical (geomorphological and hydrological) characteristics of the river. This habitat response occurs in two ways: as a direct response to the flow in the river and as a secondary response to changes in channel morphology induced by hydrologic events. For example, cobble transport necessary for the formation of Colorado pikeminnow spawning bars is related to the stream gradient, cobble size, channel cross-section, and river flow. Definition of the flow conditions necessary to develop and maintain Colorado pikeminnow spawning habitat requires an understanding of these physical relationships in the San Juan River. Similar relationships exist for other habitat types, so an understanding of the history of physical processes that have acted upon the San Juan River and a characterization of the physical description of the river as it exists today are essential to the development of flow recommendations. This chapter discusses the physical characteristics of the San Juan River, how they are related to and affected by flow regime, how this physical environment has changed as a result of human influence in the basin, and what this means for fish habitat in the river today.

GEOMORPHOLOGY

General Description

The San Juan River Basin, from headwaters to the confluence with the Colorado River, covers an area of 24,945 square miles (mi^2), and the San Juan River runs a distance of 355 mi in Colorado, New Mexico, and Utah. The basin's climatic zones range from high elevation alpine forests (up to 14,000 feet (ft)), to low elevation arid plateaus at 3,700 ft. Approximately 224 mi of river (from Piute Farms Marina, located at the interface between Lake Powell and the San Juan River, to Navajo Dam) are included in the study area (Figure 2.1). Of the remaining river, 54 mi are within the inundated area of Lake Powell, and 77 mi are upstream of Navajo Dam. These areas are not included in the SJRIP because they either are not affected by river operations (Lake Powell) or are above the present range of the two endangered fishes. The following general discussion of the San Juan River's geomorphology will be limited in scope to the study area (the portion between Piute Farms at RM 0 and Navajo Dam at RM 224).

The contact geology of the San Juan River Basin ranges in age from Precambrian to Holocene. The lithology at the headwaters of the San Juan Mountains is primarily crystalline, igneous, and metamorphic. Sedimentary sandstone, siltstone, and shale of both marine and continental origin underlie the lower river reaches found in the study area (Thompson 1982). Much of the floodplain and adjacent terraces within the study area are overlain by Quaternary sand, gravel, and cobble

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deposits. These alluvial deposits were derived from the resistant igneous and metamorphic rock of the river headwaters, thereby providing a rich source of durable cobble throughout the study area (Miser 1924, USGS 1957). The active sediment load (bedload and suspended sediment) in the system mainly originates from the highly erodible sedimentary rock and aolian sand deposits.

The river is canyon bound through approximately one-third of the study length (lower 67 mi and upper 9 mi). The remainder flows through less-confined valleys of varying widths, thus allowing some lateral channel movement.

The first major sediment source in the study area, Canyon Largo, occurs 19 mi downstream of Navajo Dam. The frequency of similar ephemeral tributaries with high sediment loads increases downstream, thereby disproportionately increasing total sediment load relative to flow in the main river. The result is an extremely high sediment load in the lower reaches of the river. This large, active sediment load in the lower river plays an important role in the formation and maintenance of instream habitat.

The total sediment transport regime has changed in the San Juan River as climatic cycles and land management have changed. Daily suspended sediment concentration data were collected for the San Juan River near Bluff, Utah, from 1930 through 1980. During the period 1930 to 1942, the system yielded approximately 47,200,000 tons of suspended sediment per year. After very high flood flows occurred in 1941 and 1942 (4.2 and 3.1 million acre-feet (maf) with peak flows at 33,800 and 42,500 cfs respectively), suspended sediment load dropped to an average of 20,100,000 tons between 1943 and 1973. Suspended sediment load dropped again after 1973, to an average of 10,100,000 tons between 1974 and 1980, although flow was slightly higher than during the 1943 to 1973 period. This latter drop in sediment load could be partially because of improved sampling techniques in recent decades; however, analyses have shown that sampling bias does not account for the entire shift and that some degree of true sediment reduction has occurred in the system (Thompson 1982).

Analysis of aerial photographs from 1934 to 1937, 1950 to 1954, 1960 to 1963, and 1988 indicates changes in the channel corresponding with reduced sediment load over time. The 1930s photography shows a sand-loaded system, particularly below Four Corners. Where the channel was not confined by canyon walls, the river was broad at high flow and heavily braided at low flow. Aerial and oblique photographs from the period show that even the canyon reach between Bluff and Piute Farms was saturated with sand.

Between the mid-1930s and the early 1950s, the channel had narrowed by an average of 29% between the confluence with Chinle Wash (RM 67) and the location of Navajo Dam (RM 224), and riparian vegetation had begun to immobilize the floodplain. Between the early 1950s and the early 1960s, the channel continued to narrow by another 3% in this reach, and vegetation became more dense. Between the early 1960s and 1988, the channel narrowed to 35% of the width measured in the 1930s. Narrowing in the later period corresponds to two major changes: the modification of flows by Navajo Dam beginning in 1962 and the encroachment of Russian olive that invaded and became established in the basin between the early 1960s and 1988. These changes resulted in

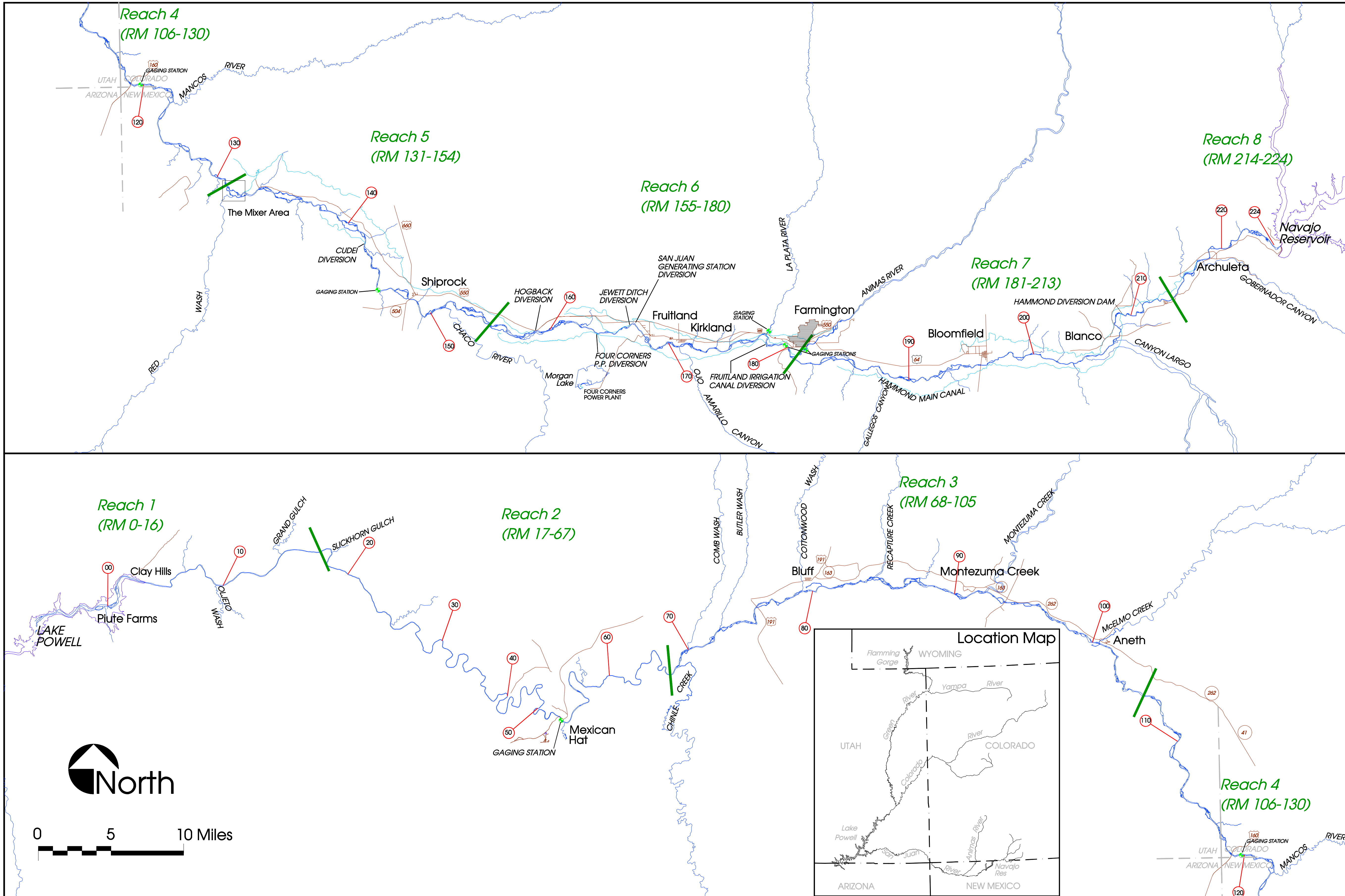

Figure 2.1. **San Juan River Basin Recovery Implementation Program (SJRIP) research study area.**

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stabilized channel banks, a somewhat deeper, narrower main channel, and fewer active secondary channels, especially in the upper reaches. In addition, the comparison of photos taken between the 1930s and 1988 indicates a substantial loss of sand from the system since the 1930s.

There is some evidence that the sediment-laden condition of the river in the 1930s was not typical of the longer term historical condition. Heavy overgrazing of the basin in the last half of the 19th century, in conjunction with appreciable El Nino effects around the turn of the century (Bryan 1925, Graf 1987, Philander 1989, Gellis et al. 1991), caused heavy erosion in the basin and system sediment loading that, over time, has been gradually moving out of the system. Although no specific evidence of San Juan River conditions prior to European settlers exists, writings from explorers in the area during the early part of the 19th century describe tributaries that are now deep, heavily eroded arroyos with broad channels as narrow, shallow streams (Bryan 1925). The difference between these pre-settlement anecdotal accounts and later photographs suggests that by the 1930s, the San Juan River had already been extensively modified by human activity.

Comparison with Green and Upper Colorado Rivers

The largest Upper Basin populations of Colorado pikeminnow and razorback sucker are found in the middle and lower Green River below Flaming Gorge Dam and in the Colorado River from the Grand Valley Diversion to Lake Powell. Because much of the available life history information on the endangered fishes was gathered from these areas, a comparison of physical features was appropriate. Although the San Juan River carries less water than either system (33% of flow of Colorado River at Cisco, Utah, and 41% of flow of Green River at Green River, Utah, 1931 to 1993), it is most comparable, geomorphologically, to the Colorado River from the Grand Valley Diversion to Cisco. The cobble bar complexes in the vicinity of Grand Junction, Colorado, are similar to those between RM 130 and RM 180 in the San Juan River, although the Colorado River complexes are larger in scale and mean cobble diameter (Bliesner and Lamarra 1995). The gradient of the San Juan River in the study reach is most similar to the Green River from Green River, Utah, upstream to Desolation Canyon and the Colorado River from Westwater Canyon upstream to the Grand Valley Diversion near Grand Junction (Figure 2.2). Compared with the Green and Colorado rivers, the San Juan River has a more uniform gradient. The Green River is characterized by low-gradient reaches (confluence with Colorado River to Green River, Utah, and from Desolation Canyon to Jensen, Utah) between high-gradient canyon reaches. The Colorado River is much flatter below Cisco than the San Juan River, having about the same gradient as the Green River below Green River, Utah.

While the San Juan, Colorado, and Green rivers have similar sediment loads (10,100,000; 9,300,000; and 9,500,000 tons/year, respectively, for the period 1974 to 1980), the San Juan River has by far the highest sediment concentration relative to the other two rivers because of its lower discharge. Sediment concentrations averaged nearly 4,800 parts per million (ppm) for the San Juan River during this period, and only 1,250 ppm and 1,500 ppm, respectively, for the Colorado and Green rivers (Hydrosphere 1998). Further, the Colorado River did not have the large shift in sediment concentration between the 1943 to 1973 and 1974 to 1980 periods exhibited in the San Juan River, and to a lesser degree, in the Green River. The sediment load in the earlier period is twice the later

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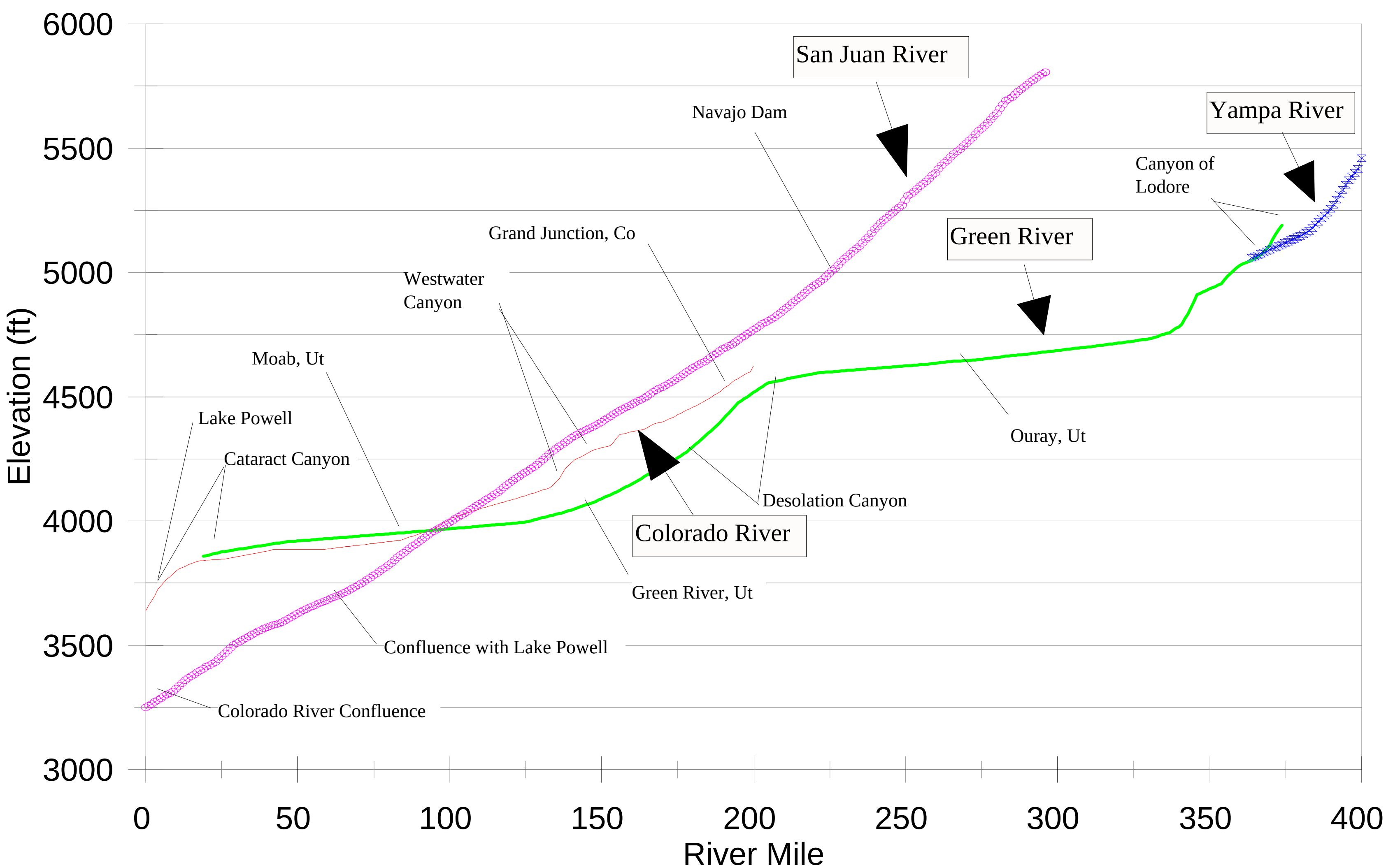

Figure 2.2. **Generalized bed profiles for San Juan, Green, Yampa, and Colorado rivers.**

period for the San Juan River and 1.6 times for the Green River, while the Colorado River was no different.

SJRIP Study Area

The study area defined by the SJRIP covers the San Juan River between the Lake Powell confluence and Navajo Dam. To more accurately assess river system response to research flows, this study area was analyzed for gross fluvial geomorphological characteristics, geology, and habitat availability. Habitat was determined by on-the-ground mapping of the river using aerial photographs developed from recent (within a few days or weeks) videography of the entire study area. Habitat types used in the mapping were similar to habitats used for other endangered fish studies in the Upper Basin and are shown in Table 2.1. The field mapping of habitat types was then digitized into a Geographic Information System (GIS).

The geomorphology varies considerably in the study area. While the gradient does not vary greatly, it is generally steeper in the upper portion of the river and flatter in the downstream portion, gradually changing over the full reach (Figure 2.2). Some cobble exists in the substrate throughout the study reach, with the exception of the lower 16 mi, but the percent composition relative to sand decreases with distance downstream. Through the valley reach (middle 150 mi), the river is primarily characterized as multithreaded (multiple channels separated by vegetated islands), with dense to moderately-dense riparian vegetation, moderate slope, and low channel sinuousity. Human-induced impacts include enhancement of riparian vegetation because of irrigation return flow, elevated groundwater adjacent to irrigated lands, and the presence of five diversions between RM 140 and RM 180 that affect bed elevation.

To better characterize the river and to allow for comparison among various reaches, eight distinct geomorphic reaches were defined based on an array of geomorphic features (Bliesner and Lamarra 1995), as described in Table 2.2 and shown in Figure 2.1. The reaches are numbered from the lower to the upper end, according to river mile. The following sections briefly describe the general characteristics distinguishing each of the reaches.

Reach 1 (RM 0 to 16, Lake Powell confluence to near Slickhorn Canyon) has been heavily influenced by the fluctuating reservoir levels of Lake Powell and its backwater effect. Fine sediment (sand and silt) has been deposited to a depth of about 40 ft in the lowest end of the reach since the reservoir first filled in 1980. This deposition of suspended sediment into the delta-like environment of the river/reservoir transition has created the lowest-gradient reach in the river. This reach is canyon bound with an active sand bottom. The thalweg meanders in the sand bottom, alternately scouring runs and sand shoals and depositing sandbars along the thalweg at all discharges. At low flow (below 1,000 cfs), backwaters form in main channel sandbars. At flows above 1,000 cfs, backwaters form in tributary mouths and invaginations in the canyon walls, and main channel backwaters are lost as the low sandbars are inundated. While this reach has the highest abundance (surface area per river mile) of backwaters among the reaches studied, the locations of backwaters are highly unpredictable and ephemeral because of the shifting thalweg, changing river flow, and varying seasonal and annual reservoir elevations.

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Table 2.1. The major habitat types mapped in the San Juan River from color plates taken from airl videography.

HABITAT	DEFINITION
Abandoned Channel (dry)	Non-flowing secondary channel.
Backwater	Typically an indentation of channel below an obstruction, water depth from < 10 cm to > 1.5 m, no perceptible flow, substrate typically silt or sand and silt. Occurs at mouths of dry secondary channels and tributaries, lower ends of eddy return channels, mouths of dry scour channels, and behind debris.
Backwater Pool	Same as backwater except maximum depth > 2 m.
Boulders	Large (> 30 cm diameter) rocks in channel.
Chute	Rapid velocity (**$**30 cm/sec) portion of channel (often near center) where gradient **$**10 cm/m. Channel profile often U- or V- shaped. Depth typically **$**30 cm. Substrate cobble or rubble and often embedded.
Cobble Bar	Bar of exposed substrate consisting primarily of cobble, usually found within the river channel but may be located along river bank.
Debris Pool	Same as pool, except organic debris such as tree limbs or tumbleweeds in pool.
Eddy	Same as pool, except water flow usually evident (but slow) and direction typically opposite that of channel or circular.
Edge Pool	Same as pool, except along shore and typically present downstream of shoreline or instream obstructions.
Embayment	Similar to backwater but formed when water pools up at upstream end of secondary channel with little or no outflow into the secondary channel.
Inundated Vegetation	Riparian vegetation inundated by flowing or non-flowing water; formed when river water overflows bank.
Irrigation Return	Channel where water is returning to river after application to agricultural fields.
Island	Dry, typically vegetated area of land surrounded by water and located within the river channel.
Isolated Pool	Small body of water in a depression, old backwater, or side channel that is isolated from the main channel as a result of receding flows.
Overhanging Vegetation	Vegetation hanging over river bank, often touching the water surface.
Pocket Water	Slackwater areas with little or no flow occurring amongst boulder clusters; usually located in canyon areas.
Pool	Area within channel where flow is not perceptible or barely so; water depth usually **$**30 cm; substrate is silt, sand, or silt over gravel, cobble, or rubble.
Rapid	Rapidly flowing (> 150 cm/sec) water over boulder substrate; typically found in steep canyon areas.
Riffle	Area within channel where gradient relatively steep, water velocity moderate to rapid (60 to 120 cm/sec), and water surface disturbed. Substrate usually cobble and portions of rocks may be exposed. Depths vary from <5 to 50 cm, rarely greater.
Riffle/Chute	Same as riffle except tail of riffle terminates in a chute (**>**120 cm/sec), gradient steeper (> 5 cm/m), and cobble substrate often embedded.
Riffle Eddy	Area adjacent to riffle where water velocity slow to moderate (5-10 cm/sec) and flow often circular. Substrate sand, gravel, or cobble. Depths usually about same as adjacent riffle or slightly deeper.
Rootwad Pile	Woody debris located within river channel.
Rootwad Pool	Pool formed by areas of rootwad piles; typically found along river margin.
Run	Typically, moderate to rapid velocity (30-90 cm/sec), and little or no surface disturbance. Depths usually 30-120 cm but may exceed 120 cm. Substrate usually sand but may be silt in slow velocity runs and gravel or cobble in high velocity runs.
Run/Riffle	Similar to run but some surface disturbance evident, typically shallower and swifter, and substrate usually cobble or rubble.
Sand Bar	Same as cobble bar but composed primarily of sand or silt substrate.
Scour Run	Same as run and where direction of flow cuts along or into bank.
Sand Shoal, Cobble Shoal	Generally shallow (< 15 cm) areas with laminar flow (< 30 cm/sec). Such areas found most often on inside bends of river meanders or at downstream ends of islands or bars.
Shoal/Riffle	Intermediate between shoal and riffle, consists of steep, lateral cobble bar with shallow (< 15 cm) and fairly rapid (> 30 cm/sec) flowing water.
Sand Shoal/Run, Cobble Shoal/Run	Same as shoal, except deeper (> 15 cm) and faster flowing (> 30 cm/sec), with either a sand or cobble substrate.
Shore Riffle	Same as riffle but along shore of channel, such areas do not extend across entire channel.
Shore Run	Same as run and where direction of flow parallel to bank with no obvious cutting.
Slackwater	Low -velocity (0 to 20 cm/sec) habitat usually along inside margin of river bends, shoreline invaginations, or immediately downstream of debris piles, bars, or other in-stream features.
Tributary	Tributary channel with flowing water entering main river channel.
Undercut Run	Same as run but with overhanging bank, often bound by rootmasses of riparian vegetation.

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Table 2.2. Reach definitions, variables considered, and their mean values within each reach used in defining geomorphically different reaches.

CATEGORY	REACH	1		2		3		4		5		6		7		8
	RIVER MILE	0-16		17-67		68-105		106-130		131-154		155-180		181-213		214-224
HABITAT - m²/mi																
High Flow	Total Water Surface	152,314	...[a]	97,161	...	199,049	...	171,983	...	206,925	...	133,983	...	102,519		150,883
	Low Velocity Types	1,920		2,015		1,481		1,893		1,861	...	946		1,241		13,642
	Riffles/Chutes	42	...	27,697		30,139		31,237		43,041	...	10,816	...	3,713	...	13,050
	Sand Type	5,704	...	363	...	15,132	...	279		3,224	...	760		1,615		337
	Cobble Type	0		43	...	3,726	...	120		147	...	632		364	...	1,692
	Islands 3 mi average	0		109	...	84,708	...	117	...	266	...	584		529		534
Intermed. Flow	Total Water	136	...	74,415	...	123,940		119,980		122,787						
	Low Velocity Types	4,646		1,192	...	2,136		2,256		2,546						
	Riffles/Chutes	3,827	...	19,013		14,373	...	252	...	38,382						
	Sand Type	43,108	...	1,962	...	8,932		6,923		3,392						
	Cobble Type	1,011		2,342	...	7,139		7,785	...	3,655						
	Islands 3 mi average	200		320	...	51,940	...	82,210	...	188,055						
Low Flow	Total Water Surface	114,291	...	72,142	...	113,314	...	104,522		107,422	...	92,933	...	77,043		94,636
	Low Velocity Types	2,239	...	890	...	1,897		2,026	...	4,328	...	8,929	...	732	...	17,921
	Riffles/Chutes	9	...	16,865		14,683		16,113	...	26,164		26,641	...	6,746	...	30,260
	Sand Type	26,112	...	1,125	...	7,195		5,526	...	2,918	...	586		1,337		0
	Cobble Type	309	...	1,522	...	2,572	...	403		3,197		2,584		3,185		2,988
	Islands 3 mi average	0		173	...	44,473	...	71,249	...	196,178	...	21,675	...	46,921		60,728
RIPARIAN VEGETATION - m²/mi																
	Cottonwood					6,094	...	2,847		4,909	...	10,043				
	Russian Olive					26,643		28,701	...	46,053	...	35,119				
	Tamarisk					25,167	...	31,224		32,536	...	19,124				
	Willow					6,592		7,393	...	3,007		4,499				
	Upland Herbaceous					1,811		7,182	...	15,801	...	9,569				
	Upland Shrub					7,897	...	7,056	...	2,349		2,647				
	Wetland Herbaceous					524		718	...	8,737		11,509				

Table 2.2. Reach definitions, variables considered, and their mean values within each reach used in defining geomorphically different reaches (continued).

CATEGORY	REACH	1		2		3		4		5		6		7		8
	RIVER MILE	0-16		17-67		68-105		106-130		131-154		155-180		181-213		214-224
CHANNEL - 3 mile average																
	Valley Width - m	102	...	66	...	1122	...	986	...	2299		2028		1957	...	574
	Channel Slope - ft/ft	0.00105	...	0.00178	...	0.00143	...	0.00164	...	0.00193	...	0.00209		0.00213	...	0.00160
	Sinuosity	1.00000		1.00001	...	1.09096	...	1.12311	...	1.16862		1.18715		1.15081	...	1.19527
STREAM CHANNEL CONTACT																
	Bedrock - m/mi					206		182		243		140				
	Eroding Bank - m/mi (Sand/Gravel/Cobble)					713	...	324		323		316				
	Contains Sand					93.6%	...	96.4%		86.2%		84.6%				
	Contains Gravel					29.7%	...	31.1%	...	7.8%	...	26.5%				
	Contains Cobble					34.6%		64.0%		62.2%		58.1%				
	Sand Only					86.1%	...	66.4%		68.7%		41.0%				
	Gravel Only					21.3%	...	9.3%		6.2%		10.8%				
	Cobble only					15.2%		21.7%		23.2%		25.3%				
CATEGORICAL VARIABLES																
	Adjacent Irrigated Area - %	0.0%		0.0%		23.7%		0.0%		83.3%		100.0%		100.0%		30.0%
	Major Tributary - Ephemeral	0		0		6		3		2		0		2		2
	Major Tributary - Perennial	0		0		2		1		1		3		1		0
	Bridge	0		1		4		1		1		2		2		1
	Diversion	0		0		0		0		1		4		1		1
	Oil Well	0		2		4		0		0		0		0		0
	Pipe Crossing	0		0		1		0		2		1		0		0
	Borrow Pit	0		1		1		0		0		0		0		5
	Pond	0		1		6		2		2		0		0		0
	Road	2		1		6		0		0		0		0		0
	Sewage Treatment	0		0		3		0		3		3		0		0

[a] ... = not equal to.
Note: Shaded rows show significant variables.
Source: Bliesner and Lamarra 1995.

Reach 2 (RM 17 to 67, near Slickhorn Canyon to confluence with Chinle Creek) is also canyon bound but is located above the influence of Lake Powell. The gradient in this reach is higher than in either adjacent reach and the fourth highest in the system. The channel is primarily bedrock confined and is influenced by debris fans at ephemeral tributary mouths. Riffle-type habitat dominates, and the major rapids in the San Juan River occur in this reach. Because of the steeper gradient, narrow canyon bottom, and low sinuosity, backwater habitats are small and scarce in this reach. Low-velocity habitats are primarily created as sand deposits in eddies below debris fans. While sandbar-associated backwaters are present, they are often associated with either debris fan/eddy complexes or eddy deposits below shoreline colluvium. Some oil development exists within an isolated area of floodplain in this reach, near the town of Mexican Hat, Utah.

Reach 3 (RM 68 to 105, Chinle Creek to Aneth, Utah) is characterized by higher sinuosity and lower gradient (second lowest) than the other reaches, and a broad floodplain, multithreaded channel, high island count, and high percentage of sand substrate. This reach has the second highest density of backwater habitats after spring peak flows, but is extremely vulnerable to change during summer and fall storm events, after which this reach may have the second lowest density of backwaters. As a result, this reach is the most highly responsive reach to extreme discharge events, primarily summer and fall storm events. While cobble is present in this reach, it is frequently mixed with sand. Areas of clean cobble are usually small and ephemeral. The active channel results in a large number of organic debris piles (dislodged Russian olive trees) at lower flow.

Reach 4 (RM 107 to 130, Aneth, Utah, to below "the Mixer") is a transitional reach between the upper cobble-dominated reaches and the lower sand-dominated reaches. It has the most bedrock contact of any reach. Sinuosity is moderate compared with other reaches, as is gradient. Island area is higher than in Reach 3 but lower than in Reach 5, and the valley is narrower than in either adjacent reach. Total water surface area is somewhat less at all flows than in the adjacent reaches. River banks are more stable in this reach than in Reach 3, and about the same as in Reaches 5 and 6. Backwaters in this reach are subject to perturbation from summer and fall storm events, but Reach 4 is not as responsive as Reach 3. Backwater habitat abundance is low overall in this reach (third lowest among reaches) and there is little clean cobble. Perturbation of secondary channels because of summer and fall storm discharges occurs frequently in this reach. One perennial tributary, the Mancos River, enters the San Juan River in this reach.

Reach 5 (RM 131 to 154, the Mixer to just below Hogback Diversion) is predominantly multithreaded with the largest total wetted area (TWA) and largest secondary channel area of any of the reaches. Secondary channels tend to be longer and more stable than in Reach 3 but fewer in number overall. Riparian vegetation is more dense in this reach than in lower reaches but less dense than in upper reaches. Cobble and gravel are more common in channel banks than sand, and clean cobble areas are more abundant than in lower reaches. Channel gradient in Reach 5 is steeper than in all lower reaches but flatter than in Reaches 6 and 7. This is the lowermost reach where adjacent irrigated lands and irrigation return flow influence riparian vegetation and bank stability, and contribute to groundwater accretion. The river valley is broadest in this reach. One perennial tributary, Chaco Wash, enters the San Juan River in this reach. This is the lowermost reach

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containing a diversion (Cudei). Backwaters and spawning bars in this reach are much less subject to perturbation during summer and fall storm events than the lower reaches.

Reach 6 (RM 155 to 180, below Hogback Diversion to confluence with the Animas River) is predominately a single channel, with 50% fewer secondary channels than Reaches 3, 4, or 5. Cobble and gravel substrates dominate, and cobble bars with clean interstitial space are more abundant in this reach than in any other. Irrigated land adjoins the river for the full length of this reach, often on both sides of the river. There are four diversions that may impede fish passage in this reach (Figure 2.1). Backwater habitat abundance is low in this reach, with only Reach 2 having less. Gradient is the second steepest of all reaches, although about 10% of the elevation change occurs at the diversions, making the effective slope about the same as that in Reach 5. Two perennial tributaries enter in this reach: the LaPlata River, which carries little water to the San Juan River except during runoff, and the Animas River, which is the largest tributary to the San Juan River in the study area. A third tributary, the Ojo Amarillo, is naturally ephemeral but is effectively perennial at present because of irrigation return flow. Irrigation return flow influences riparian vegetation and groundwater accretion in this reach. The channel has been altered by dike construction in several areas to control lateral channel movement and overbank flow.

Reach 7 (RM 181 to 213, Animas River confluence to between Blanco and Archuleta, New Mexico) is similar to Reach 6 in terms of channel morphology, with about the same secondary channel count, TWA, and valley width. Irrigated land adjoins most of this reach on both sides of the river, and groundwater accretion contributes to an increase in grass understory. The river channel is very stable. The reduction in magnitude of peak flows with the construction of Navajo Dam caused a reduction in overall shear stress and a reduced ability to move large-grained embedded cobble. In addition, much of the river bank has been stabilized and/or diked to control lateral movement of the channel and overbank flow. While the dominant substrate type is cobble, armoring has occurred that, coupled with the bank armoring and grass understory, limits availability of new cobble sources within this reach. Water temperature is influenced by the hypolimnetic release from Navajo Dam and is colder during the summer and warmer in the winter than the river below the Animas confluence. Sediment load is also reduced because of the sediment-trapping influence of the dam and limited tributary influence resulting in relatively clear water compared with downstream reaches.

Reach 8 (RM 213 to 224, between Blanco and Archuleta and Navajo Dam) is the most directly influenced by Navajo Dam, which is situated at its uppermost end (RM 224). This reach is predominantly a single channel, with only four to eight secondary channels, depending on the flow. This reach has the lowest number and TWA of secondary channels of any reach above the lower canyon (Reaches 1 and 2). The valley narrows in this reach, with less irrigation influence and less artificial stabilization of the channel. Cobble is the dominant substrate type, and because lateral channel movement is less confined in this reach, some loose, clean cobble sources are available from channel banks. In the upper end of the reach, just below Navajo Dam, the channel has been heavily modified by excavation of material used in dam construction. In addition, the upper 6.2 mi of this reach above Gubernador Canyon are essentially sediment free, resulting in the clearest water of any reach. Because of Navajo Dam, this area experiences much colder summer and warmer winter temperatures. These cool, clear water conditions have allowed development of an intensively managed blue-ribbon trout fishery to the exclusion of the native species in the uppermost portion of the reach.

HYDROLOGY

No hydrology data exist for the San Juan River that pre-date the early water development in the basin. While the pre-Navajo Dam hydrograph was natural in shape, it was depleted in volume by about 16% from natural conditions, with most of the depletion coming during the summer months. Since the depletion prior to Navajo Dam was relatively small and the flow was not regulated by major storage reservoirs, the conditions during the pre-dam period are used to judge effects of later development and the value of future modification of the hydrology for the benefit of the endangered fishes.

Daily flow data recorded by the U.S. Geological Survey (USGS) (Hydrosphere 1998) from 1929 through the present are available for the San Juan River. These data have been used to analyze the changes in hydrology with time. The San Juan River's hydrology was very different before regulation by Navajo Dam began in 1962. Hydrology is discussed separately for the two periods (pre- and post-dam eras) to contrast the change. In addition, research flow period hydrology is discussed separately, indicating the restorability of more natural hydrologic conditions.

Pre-Navajo Dam (1929 to 1961)

The San Juan River is typical of dynamic rivers in the southwestern United States that are characterized by large spring snowmelt peak flows, low summer and winter base flows, and high-magnitude, short-duration summer and fall storm events. For the period 1929 to 1961 at the USGS gage station near Bluff, approximately 72% of the total annual discharge occurred during spring runoff between March 1 and July 31. The median daily peak discharge (peak daily mean discharge as recorded by USGS does not represent instantaneous peak flow) during spring runoff was 10,500 cfs, with a range of 3,810 to 33,800 cfs. The average pre-dam hydrograph (average of all daily flows from 1929 to 1961) for the San Juan River near Bluff is shown in Figure 2.3.

While the spring runoff produces the largest total volume of water, about 30% of the time the yearly peak flow does not occur during spring. Furthermore, the maximum daily average discharge for the period during spring is 33,800 cfs, while the maximum daily average discharge annually is 42,500 cfs. This difference is because of summer and fall storm events. These summer and fall storm events have a small impact on the total water supply, but because of the heavy sediment load, these events substantially influence habitat formation and maintenance.

The magnitude of summer and fall storm events in the San Juan River Basin is higher in relation to the median flow than those noted in the Colorado and Green river basins. In the San Juan River, 97% of the years between 1929 and 1961 had at least one storm event during the period of August

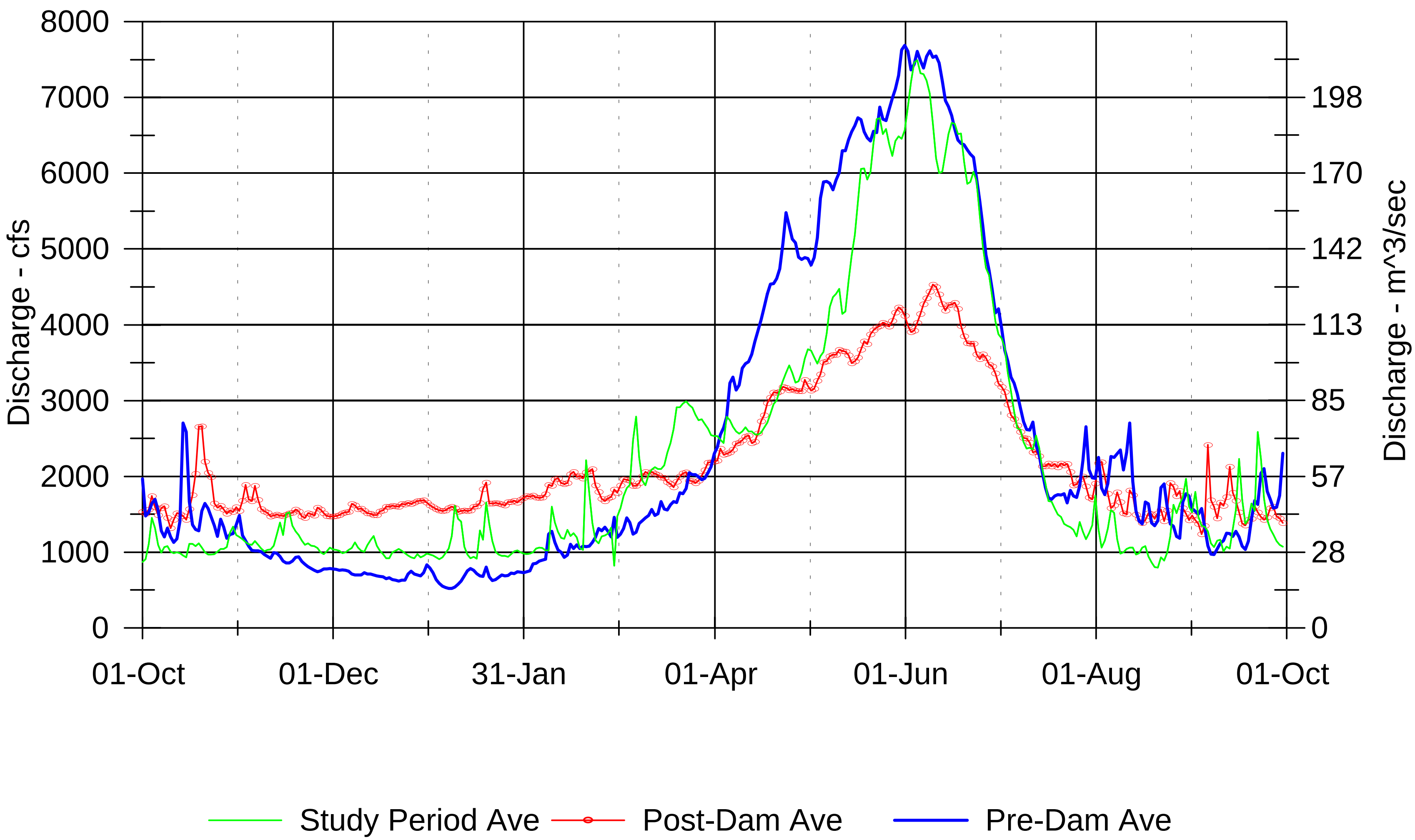

Figure 2.3. **San Juan River near Bluff, Utah, average hydrographs for pre-dam, post-dam, and 7-year research period.**

through November that resulted in flows three or more times the average base flow (mean daily flow of the river during nonsnowmelt, nonstorm runoff periods). Fifty-five percent of the time, the resultant discharge was eight or more times the base flow, with a maximum daily mean peak to average base-flow ratio of nearly 13. In comparison, neither the Green River gage nor the Colorado River gage has ever recorded a storm event with a daily mean peak greater than five times the base flow.

The frequency of summer and fall storm events is also higher in the San Juan River Basin compared with the Green or Colorado rivers. For the period 1929 to 1961, the San Juan River Basin had nearly five times as many days per month with storm events above two times the average base flow. The comparison of average monthly ratios of maximum mean daily flow to daily average flow for the month for the three rivers, along with the average duration of flows above two times the base flow for the three rivers, appears in Table 2.3.

Table 2.3. Comparison of storm magnitude and frequency for the Colorado River at Cisco gage, Green River at Green River gage, and San Juan River near Bluff gage.

	RATIO AVE MAX DAILY /AVG MONTHLY DISCHARGE			AVG NO. OF DAYS FLOW EXCEEDED 2 TIMES AVE MONTHLY FLOW		
Month	**Colorado R. at Cisco**	**Green R. at Green R.**	**San Juan R. near Bluff**	**Colorado R. at Cisco**	**Green R. at Green R.**	**San Juan R. near Bluff**
Oct	1.59	1.46	3.08	0.36	0.12	3.31
Nov	1.24	1.24	1.87	0.00	0.12	0.90
Dec	1.26	1.39	1.75	0.06	0.00	0.66
Jan	1.22	1.25	1.83	0.00	0.00	0.84
Feb	1.24	1.34	1.96	0.00	0.06	1.98
Mar	1.41	1.80	1.91	0.06	2.16	1.38
Apr	1.89	1.74	1.81	1.98	0.96	1.14
May	1.72	1.60	1.78	0.96	0.30	1.02
June	1.54	1.42	1.75	0.18	0.00	0.84
July	1.87	1.90	2.70	1.08	1.56	4.15
Aug	1.75	1.62	3.52	0.84	0.24	5.53
Sep	1.84	1.66	3.78	0.78	0.36	4.99
Ave	1.55	1.54	2.31	0.53	0.49	2.23

High annual discharge variability is also a characteristic of the San Juan River. The annual discharge near Bluff for the pre-dam period ranged from 618,000 af to 4,242,000 af with a median of 1,620,000 af. Furthermore, the hydrology appears to follow cyclic patterns of multiple years of high flow followed by multiple years of low flow where up to 4 sequential years may have total annual discharge less than 1,000,000 af.

Although the pre-dam era is considered relatively natural, irrigation and other water development depletions have occurred annually since the settlement of the San Juan River Basin in the late 1800s. As a result, the pre-dam hydrology was not pristine. Summer and winter base flows during the pre-dam period were low but variable. Typically, summer flows were lowest because of irrigation depletions, and periods of near zero flow were not uncommon. Flows of less than 50 cfs have a recurrence frequency of 29%, with an average duration of 11 days. Monthly mean flows were as low as 65 cfs.

Post-Dam Period (1962 to 1991)

Completion of Navajo Dam and subsequent dam operation substantially altered the natural hydrograph of the San Juan River below the dam. Although the Animas River ameliorated some effects of the dam and maintained an elevated spring runoff, the system overall experienced an appreciable reduction in magnitude and change in timing of the annual spring peak. In years of high runoff, dam releases began earlier than under pre-dam conditions to allow space in the reservoir to store the runoff. In the wettest years, releases continued through the peak season (May and June), but during many years, dam releases in May and June were close to the average base release of about 600 cfs. The peak discharge during the post-dam period averaged 54% of the spring peak during the pre-dam period.

Base flows were substantially elevated in the post-dam compared with the pre-dam period. The median monthly flow for the base-flow months of August through February averaged 168% of the pre-dam period. Minimum flows were also elevated. The near-zero flow periods were eliminated, with a minimum monthly flow during base-flow periods of 250 cfs compared with 65 cfs for the pre-dam period. Summer storm runoff was not directly affected by the dam, especially in terms of high sediment input, because these events can be generated below the influence of the dam. Hydrologic statistics from the two periods are compared in Table 2.4. The average post-dam hydrograph (average of daily flows for 1962 to 1991) is shown in Figure 2.3, allowing comparison with the average pre-dam hydrograph.

Research Period (1992 to 1997)

Also shown in Table 2.4 are the statistics for the research flow period (1992 to 1997), compared with the pre- and post-dam periods. While some more-natural hydrologic conditions were restored during the 7-year research period, peak magnitude was not matched because of outlet work operating restrictions at Navajo Dam and uncertainty about channel capacity above 5,000 cfs. Because of the short period of record, the statistics are not directly comparable, but these numbers give an idea of how this period compares with the other two periods. On average, this period was about 8% wetter than the pre-dam and 19% wetter than the post-dam period, with a much smaller range of annual flows than during either period. Figure 2.3 shows the average hydrograph for the 7-year research period for comparison with pre- and post-dam hydrographs. Because 1991 was a control year without dam reoperation, it is included with the post-dam period rather than the 7-year research

Table 2.4. Comparison of hydrograph statistics for pre-dam (1929 to 1961), post-dam (1962 to 1991), and research periods (1992 to 1997) for the San Juan River near Bluff, Utah.

PARAMETER	1929-1961 PRE-DAM PERIOD			1962-1991 POST-DAM PERIOD			1992-1997 STUDY PERIOD		
	Average	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**
Peak Runoff - cfs	12,409	3,810	33,800	6,749	2,660	15,200	8,772	3,280	11,600
Runoff (Mar-Jul) - af	1,263,890	352,551	3,361,882	891,712	177,190	2,458,190	1,132,899	421,001	1,681,192
Runoff (total annual) - af	1,750,643	618,101	4,241,998	1,587,242	611,196	3,266,017	1,628,165	797,821	2,271,912
Runoff (total annual) - af, adjusted to pre-dam depletions							1,898,000	1,068,000	2,542,000
	Years	**Total Yrs**	**Frequency**	**Years**	**Total Yrs**	**Frequency**	**Years**	**Total Yrs**	**Frequency**
Peak>10,000 cfs	18	33	55%	6	30	20%	2	6	33%
Peak>8,000 cfs	22	33	67%	11	30	37%	5	6	83%
Peak>5,000 cfs	30	33	91%	16	30	53%	5	6	83%
Peak>2,500 cfs	33	33	100%	27	30	90%	6	6	100%
AF>1,000,000	18	33	55%	12	30	40%	4	6	67%
AF>750,000	22	33	67%	14	30	47%	5	6	83%
AF>500,000	30	33	91%	20	30	67%	5	6	83%
	Ave Date	**Std Dev**		**Ave Date**	**Std Dev**		**Ave Date**	**Std Dev**	
Peak Date	31-May	23		Jun-04	35		07-Jun	8	
Flow duration	Avg all yrs	Avg flow yrs	Maximum	Avg all yrs	Avg flow yrs	Maximum	Avg all yrs	Avg flow yrs	Maximum
Days>10,000 cfs	14	27	76	3	15	48	2	7	8
Days>8,000 cfs	23	34	81	8	22	84	10	12	22
Days>5,000 cfs	46	51	108	28	52	124	51	62	109
Days>2,500 cfs	82	82	140	67	74	150	90	90	137
Base Flow	Median	High 10%	Low 10%	Median	High 10%	Low 10%	Median	High 10%	Low 10%
August	1,156	4,782	300	1,566	3,242	407	1,107	2,497	476
September	1,033	3,383	201	1,174	3,279	478	1,286	2,760	861
October	1,000	2,551	400	1,608	3,317	635	1,089	1,521	716
November	752	1,387	497	1,199	3,205	765	1,141	1,479	982
December	667	1,325	434	1,288	3,389	711	1,049	1,187	769
January	609	1,267	471	1,440	3,226	582	934	2,053	739
February	872	2,265	572	1,661	3,188	823	1,006	2,256	807

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period. The 7-year research period was preceded by a significant drought from 1988 to 1992. Figure 2.4 shows the annual hydrographs at Four Corners for 1987 to 1990, and Figure 2.5 shows the annual hydrographs for the San Juan River at Four Corners for the 7-year research period (1991 to 1997).

WATER TEMPERATURE

Water temperature data for the San Juan River have been collected and reported by the USGS since 1948. Consistent data collection began in 1950 or 1951 at most stations. While there are missing data for all stations, sufficient data exist to examine the effect of Navajo Dam on water temperatures below the dam. Figure 2.6 presents the 5-day running average daily water temperature for the period of available record before and after construction of Navajo Reservoir at Archuleta and Shiprock, New Mexico. The cooling effect of the reservoir is obvious at both locations, although it is much more pronounced at Archuleta because of the dam's proximity. As a check on the comparison of these two periods, the temperature conditions for the Animas River at Farmington, New Mexico, were compared, indicating much less difference between the two periods than between either of the San Juan River sites. Based on the results shown in Figure 2.6 and assuming a 20E C threshold for Colorado pikeminnow spawning on the descending limb of the hydrograph (see Chapter 3), it appears that the pre-dam condition at Archuleta would have allowed spawning at that site by about the same date as the post-dam condition at Shiprock. The post-dam conditions at Archuleta were likely too cold for successful Colorado pikeminnow spawning, and the threshold temperature was reached about 2 weeks later on average at Shiprock.

Nine temperature recorders were installed in the San Juan River in the summer of 1992 (Bliesner and Lamarra 1995, 1996). Figure 2.6 shows the average daily temperature of the San Juan River for the period 1992 to 1997 projected for Shiprock (correlation to Farmington and Montezuma Creek). The plot shows a temperature depression during runoff (May and June) that was attributable in part to cooler temperatures in the Animas River during this period than during the 1964 to 1986 period. However, the cooler Animas River water accounts for only about one-half of the temperature difference between the 1964 to 1986 and the 1992 to 1997 San Juan River temperature at Shiprock. The increased release of the cool reservoir water into the San Juan River suppressed the water temperature about 1.5E C during runoff. Thus, the threshold spawning temperature at Shiprock was delayed about 1 to 2 weeks from the post-dam period (1963 to 1991).

HABITAT

Aquatic habitat is generally described by either its related bedform, such as cobble bar or shoal, or the effective hydraulic feature, such as riffle, run, or eddy. The approach used usually depends on the desired characteristic of the feature. For example, cobble bars are a bedform described as aquatic habitat because the interstitial spaces and substrate size are important for reproductive success. Alternatively, eddies are described as habitat for adults because the hydraulic circulation provides

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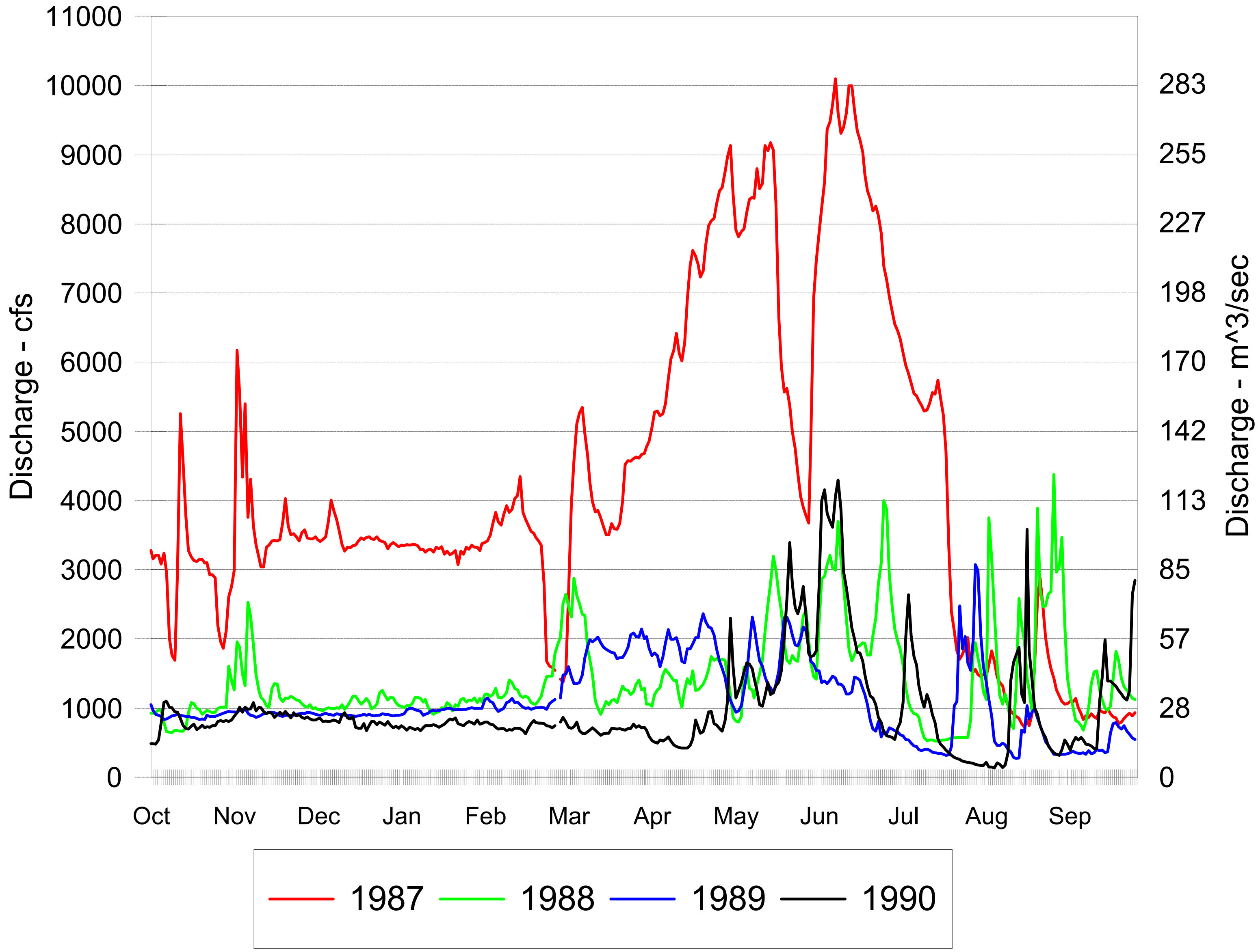

Figure 2.4. **Annual hydrographs for the San Juan River at Four Corners for 1987 to 1990.**

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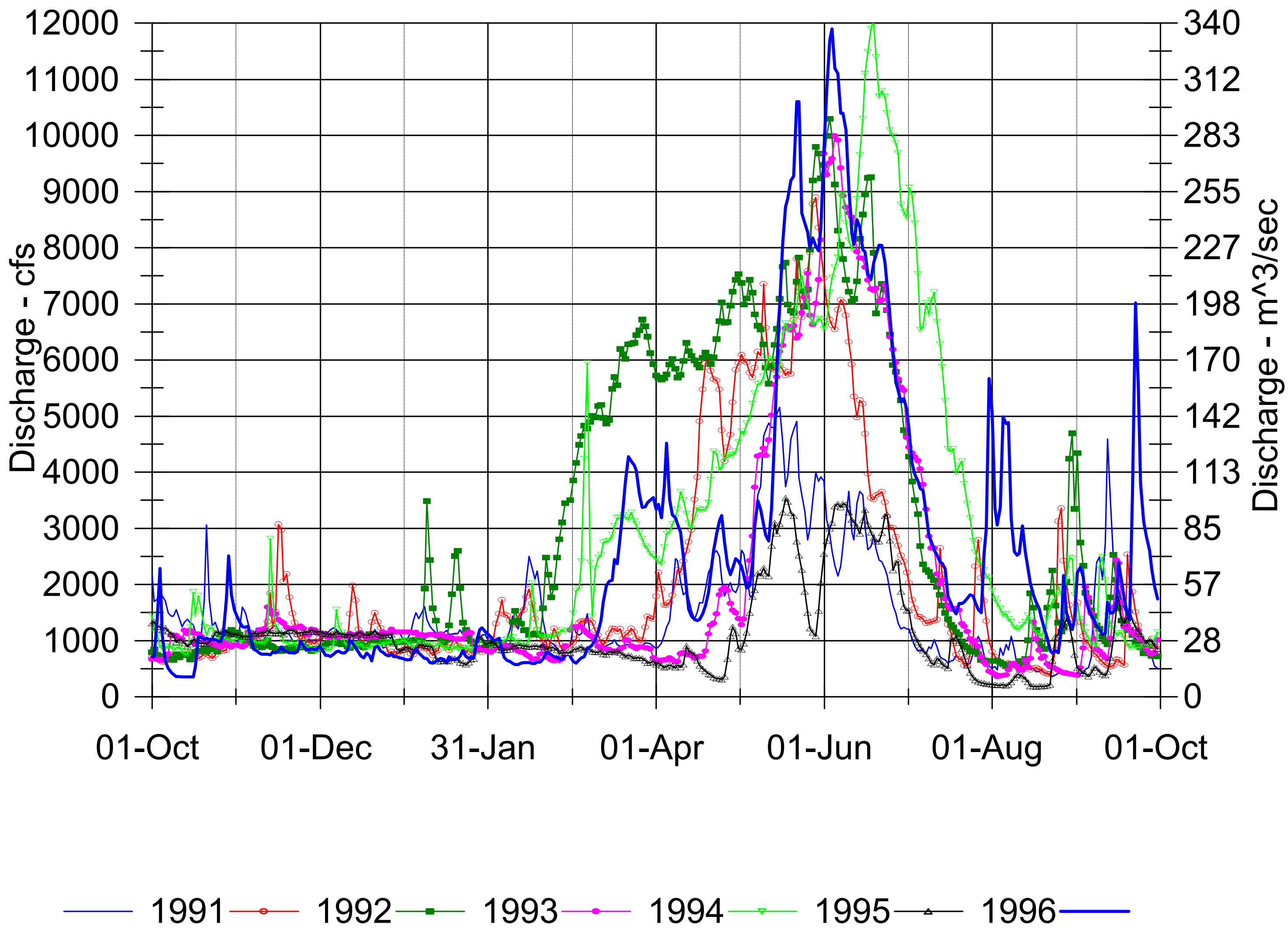

Figure 2.5. Annual hydrographs for the San Juan River at Four Corners for 1991 to 1997.

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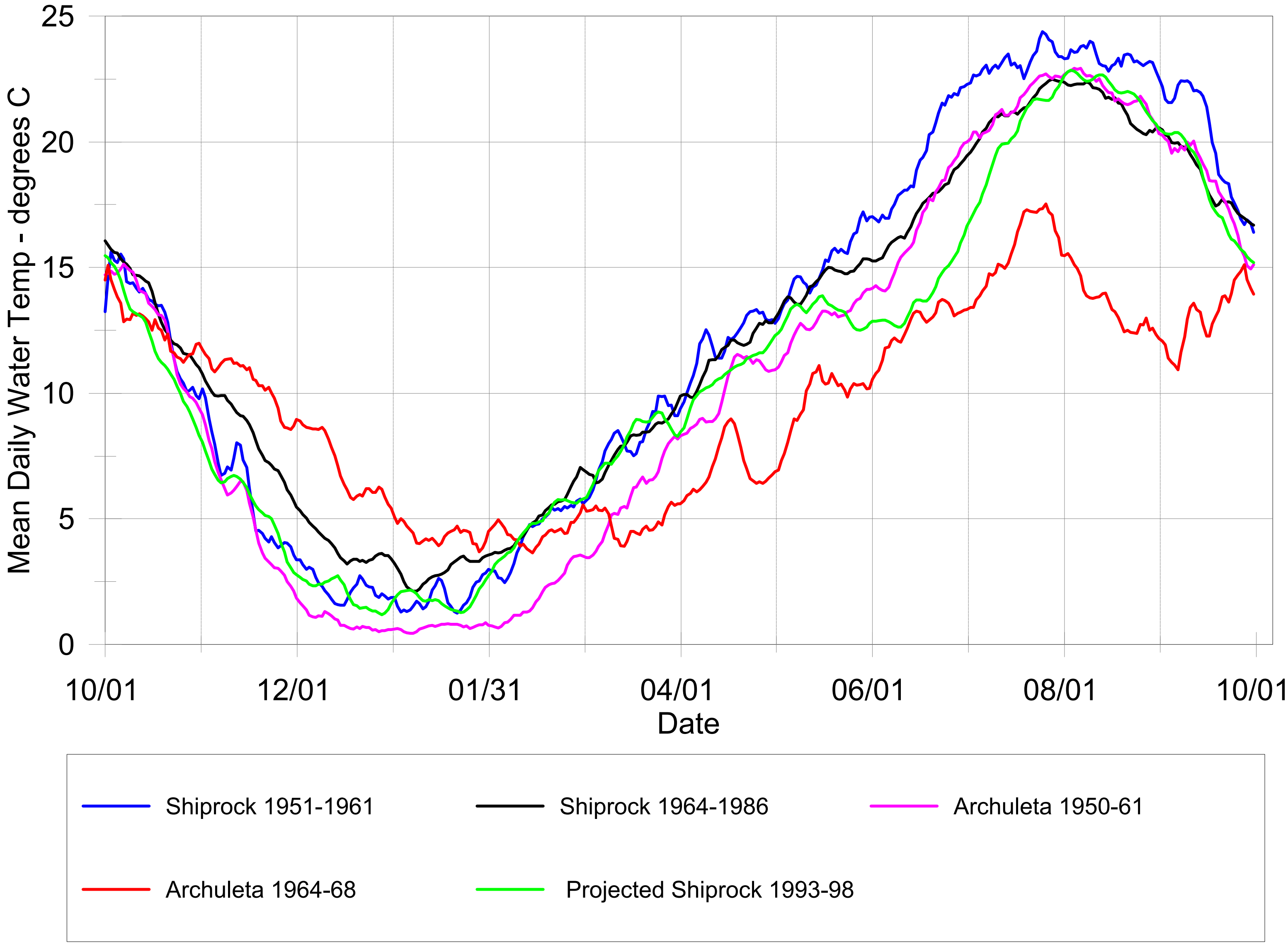

Figure 2.6. **Mean daily water temperature for the San Juan River at Archuleta, New Mexico, and at Shiprock, New Mexico, during pre-dam and post-dam conditions.**

a concentration and deposition of food items. Channel geomorphology and hydrology directly affect aquatic habitat conditions, both in quantity and quality. Several habitat types have been identified as important and perhaps limiting to the endangered Colorado pikeminnow and razorback sucker; these habitats have been the focus of habitat studies. In particular, spawning habitat may limit reproduction, and nursery habitat (backwaters and low-velocity habitat) is known to be crucial to the survival of young Colorado pikeminnow in their first year (Holden and Selby 1978, Valdez et al. 1982). In addition, certain hydraulic habitats are important for adult feeding and resting. The following discussion describes some specific relationships between flow regime and habitat quantity and quality, as well as the relationships between river reach and habitat quantity and quality that are known to be important to the endangered and other native species.

Habitat Quantity

Colorado pikeminnow and razorback sucker spawning habitat (clean cobble/gravel) maintenance depends upon flows producing sufficient shear stress to transport cobble and remove sand from the interstitial spaces. These conditions may occur during cobble bar formation at relatively high flows in the system or during cobble bar reshaping at somewhat reduced flows on the descending limb of the spring peak. Regular reworking and mobilization of the cobble are required to prevent the armoring or embedding of cobble substrates by the predominately sand bedload.

Certain flows are required on an annual basis to shape substrate and scour fine sediment to create and maintain backwaters and other low-velocity habitats. Both the magnitude and duration of the spring peak can affect the quality and quantity of backwater habitat. Large, deep, more-permanent backwaters have been noted as preferred by young-of-the-year (YOY) Colorado pikeminnow over shallow, ephemeral backwaters (Holden 1977). High sediment input during summer and fall storm events fills low-velocity habitats with sediment, reducing the availability and quality of these habitats during crucial post-larval Colorado pikeminnow growth periods. The extent to which these habitats become filled, and subsequently unavailable to fish during late summer base flows and storm events, depends on the duration and magnitude of the spring peak flows that form and maintain them relative to the summer flows that may fill or destroy them.

The distribution and abundance of all habitat types (bedforms and hydraulic) are affected by both snowmelt runoff flows and base flows. To characterize the distribution and abundance of habitat in the San Juan River and to measure the response of habitat to flows over a 7-year period, aquatic habitat was mapped on 11 separate occasions during different seasons, years, and flow levels. Mapping has been completed for the entire 224 mi of the San Juan River from Lake Powell to Navajo Dam, but the most intensively mapped reach was between RM 154 and RM 2, constituting Reaches 1 to 5.

As defined in Table 2.1, 37 habitat types were identified to map the river, and these types were divided into the eight general categories shown in Table 2.5. Mapping occurred in the field using recent aerial videography from 1991 to 1997 as the base map. Maps were entered into a GIS for analysis. Processing the data in the GIS produced coded polygons (habitats) for which surface areas

Table 2.5. Eight general categories of habitat types on the San Juan River.

LOW VELOCITY TYPES	RUN TYPES	RIFFLE TYPES	BACK-WATER TYPES	SHOAL TYPES	SLACK-WATER TYPES	VEGETATION ASSOCIATED HABITAT TYPES	OTHER TYPES
pool	shoal/run	riffle	backwater	sand shoal	slack-water	overhanging vegetation	isolated pool
debris pool	run	shore riffle	backwater pool	cobble shoal	pocket water	inundated vegetation	cobble bar
rootwad pool	scour run	riffle chute	embayment				rootwad pile
eddy	shore run	shoal/ riffle					abandoned channel (dry)
edge pool	undercut run	chute					sand bar
riffle eddy	run/riffle	rapid					tributary
							island
							irrigation return
							boulders

were computed and sorted individually. The data were then retrieved and analyzed by cross-tabulation of the factors being correlated (e.g., habitat area by RM).

To compare habitat availability at various flow levels, the mapping data were summarized for three flow levels: <700 cfs; 3,000 cfs; and >7,000 cfs (Figure 2.5). Run-type habitats (Table 2.5) were the most common for all San Juan River flow levels (Figure 2.7). These habitat types were 81.5%, 84.3%, and 79.6% of the TWA for the high-, medium-, and low-flow mapping runs, respectively (Figure 2.7).

Riffle and shoal habitat types represented the second most abundant habitat types found in the San Juan River at medium and low flows. Riffle habitats were found to be 5.7% at medium flows and 6.0% at low flows, while shoals were 3.2% and 9.5% for medium and low flows. At high flows, riffles and shoals were only 0.5% and 2.3% of the TWA, respectively. However, inundated vegetation was 5.6% of the TWA at high flows, the only flows where this habitat type was greater than 1% of the TWA.

Slackwaters and low-velocity habitats (embayments, eddies, pools, etc.) together made up 3.4% of high-flow habitats, 3.6% of medium flows, and 3.5% of low flows. Backwater types had the lowest overall percent of TWAs with 0.5%, 0.3%, and 0.9% for high, medium, and low flows, respectively.

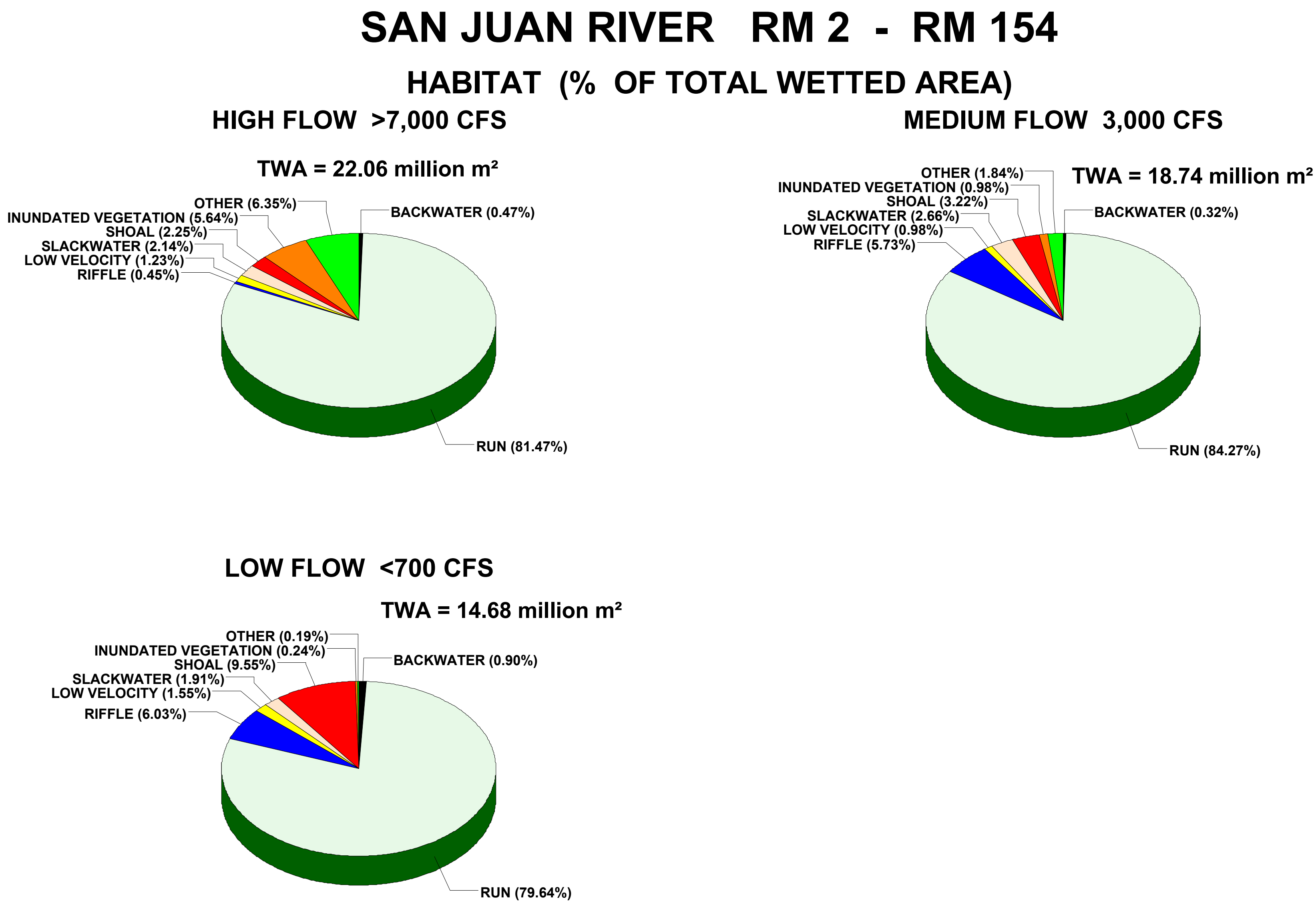

Figure 2.7. **Habitat types as a percent of total wetted area (TWA) for the San Juan River at three flow levels.**

Based upon the habitat-use information gathered for many of the native fishes and especially for the two endangered species in the Upper Basin, as well as on the San Juan River (see Chapters 3 and 4 for more detail), many of the habitats that are relatively rare in the San Juan River are typically heavily used. Even though relatively rare in the San Juan River, the quantity of many of these habitats varies with flow. Based on Figure 2.7, low-velocity habitat quantity makes up a larger amount of the available habitat at low flows (1.55% of habitat), and is lowest at intermediate flows (0.98% of habitat). Backwaters, as a percent of total habitat, nearly double (0.47% to 0.90% of habitat) from high flows (>7,000 cfs) to low flows(<700 cfs). The percent of shoal area also dramatically increases at low flows (2.25% to 9.55% of habitat) compared with high flows.

Pools and eddies are also important native fish habitats, and both are included in the low-velocity types (Table 2.5). An analysis similar to the one shown in Figure 2.7 reveals that pool habitat is also somewhat lower at high flows, but eddy habitat tends to increase with flow.

Run habitats are the most common habitat (as a percent of the TWA) at all flows. Although runs are used by the native fish community, the less numerous low-velocity backwater, shoal, and riffle habitats are used more than would be expected based on their availability, and they are generally considered more important than runs. These habitats, which tend to reach greatest densities at low flows, show distinct spatial patterns throughout the river. Figure 2.8 shows the longitudinal distribution of the eight major habitat types by geomorphic reach during September 1995 at a low flow of 1,000 cfs.

In Reach 1 (which is canyon bound but under the influence of Lake Powell), habitats other than runs were dominated by shoals comprising 20% of the total habitat. These shoals were midchannel features with a shifting sand substrate. Reach 2, which is also canyon bound, had riffles and riffle-associated slackwaters as the second most common habitat. Few shoals were present in this steeper gradient reach of the river. Reach 3 appeared to be a transitional reach between the canyon reaches (1 and 2) and the multichannel upper reaches (4 to 7), with intermediate levels of riffles, slackwaters, and shoals. Reaches 4 through 7 tended to be dominated more by run habitat than the reaches above (Reach 8) or below (Reaches 1 to 3). Reach 8, immediately below Navajo Reservoir, was mostly single channel with shallow gradient and numerous shoals. Reach 3 contained the highest amount of backwater habitat at base flow (1.54% of TWA). With the exclusion of runs and backwaters, the remaining minor habitat types appear to be equally distributed as a percent of the TWA in Reaches 4 to 7.

In summary, habitat quantity varies in the San Juan River with both flow level and location in the river. Run habitats dominate, and many of the other habitats important to the native fish community are relatively rare in the system, but specific flow levels can maximize the amount of these habitats.

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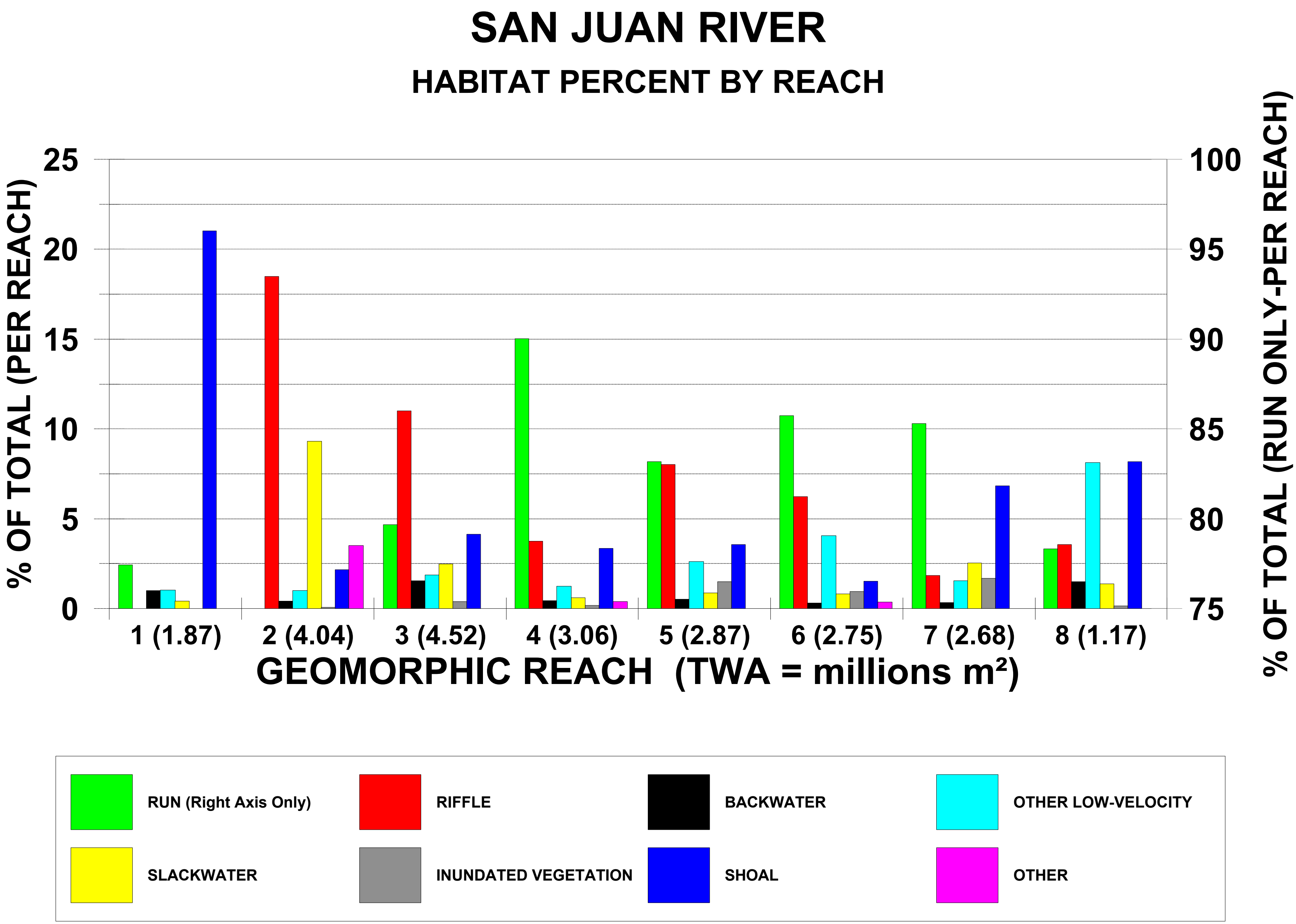

Figure 2.8. **The distributions of the major habitat types by geomorphic reach for a base-flow condition (September 1995).**

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Habitat Quality

Habitat quality relates to the features (size, depth, productivity) of a particular habitat that define how well that habitat may support the native fishes. The primary factor that negatively affects habitat quality in the San Juan River, as well as most other rivers, is fine sediment (silt and sand).

Fine sediment generally enters the river during spring runoff and storm activity. During spring runoff, flows are typically high enough to move the fine sediments down the system or deposit them on islands and shorelines. During storm-event flooding, flows are typically insufficient to move the heavy sediment load brought in from tributaries downstream or to shoreline areas, resulting in deposition in various habitats. The filling of interstitial spaces in cobble/gravel substrates of higher-velocity habitats such as runs and riffles tends to reduce their quality by limiting the use of those spaces for primary and secondary production, as well as reducing their use as spawning habitat for native fishes.

Lower-velocity habitats such as backwaters and eddies tend to have finer substrate than runs and riffles (Table 2.1), but their quality can also be reduced by the addition of silt and fine sand that accumulate during storm flood events. These low-velocity habitats can fill with silt and fine sand, effectively reducing their depth and smothering primary and secondary production areas. The frequent late summer and fall storm events in the San Juan River cause dramatic reductions in habitat quality in low-velocity habitats because of filling by fine sediments. Bliesner and Lamarra (1995) reported on changes in habitat quality in the San Juan River between samples in November and December 1994 because of a storm event. Sedimentation of 8 to 15 cm of sand occurred in a run in RM 155 during a 3-week period that included a major storm event, and both backwater habitat number and depth were affected by fall storms that year. Perturbation of habitats in the San Juan River because of late summer and fall storm events is likely the most common form of habitat quality degradation in this system (Bliesner and Lamarra 1995, UDWR 1998). Reductions in habitat quality because of fine sediment can be reversed by high flows that scour the fine sediments from the habitats.

Riffle and run habitats are the two most dominant habitat types relative to the TWAs found in the San Juan River (Figure 2.7) and were selected for investigation of general habitat quality in the study area. During 1994, 1995, and 1996, primary and secondary biomass, as well as physical substrate characteristics, were quantitatively determined for replicate run and riffle sites within each geomorphic reach of the San Juan River to provide an estimate of habitat quality. Parameters measured to estimate production were invertebrate dry weight, detritus dry weight, periphyton dry weight, and the total dry weight of all three combined. Substrate parameters measured percent embeddedness and depth of embeddedness primarily related to embeddedness of the cobble substrates. Another measured parameter, D_{50}, estimated the size (diameter) of the median substrate in the study area based on measurement of 100 individual cobbles. Cobble substrates are typically more productive than sand substrates, and more embeddedness generally is related to poorer biological productivity (Hynes 1970, Farnworth et al. 1979).

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In order to characterize longitudinal patterns in habitat quality in riffles and runs, the data were sorted by geomorphic reach and averaged over all sample periods. Tables 2.6 and 2.7 contain the mean and standard errors for each parameter when summed over sample period and geomorphic reach.

The mean depth to embeddedness values for each geomorphic reach did not demonstrate significant differences in riffles or runs by geomorphic reach, but did demonstrate significantly greater depth levels in riffles compared with runs for a given geomorphic reach. Although some spatial patterns were evident for mean substrate sizes in geomorphic reaches in riffles and runs, the most obvious differences were the uniformly larger substrates in riffles compared with runs in all geomorphic reaches (Table 2.6). The only exception was in Reach 6, where the riffle and run D_{50} values were similar. Percent embeddedness was lowest in Reach 8, immediately below Navajo Dam. For riffle habitats, Reaches 6 and 7 were the most embedded, although they were not statistically different from the other downstream reaches.

The spatial patterns observed in the biological components (periphyton, macroinvertebrates, and detritus) were very similar, with the upper reaches of the river (Reach 6, 7, and 8) being higher than the middle reaches (Reach 3, 4, and 5). Reach 2 had the lowest concentrations of organic materials, and Reach 1 had densities equal to or greater than the middle and upper reaches. These patterns are exemplified by the macroinvertebrates (Table 2.6).

The information used to compare river reaches was also used to compare runs and riffles over time. The mean and standard error for each parameter when summed over sample period and geomorphic reach is shown in Table 2.7. Substrate characteristics demonstrated significant differences between riffles and runs, as well as seasonal changes (Table 2.7). For example, depth to the embedded layer was significantly greater in riffles compared with runs, which is reasonable because of the higher velocities of riffles. In addition, both riffles and runs had significant increases in the depth to the embedded layer between April 1994 and November 1994, a period that spanned the spring runoff when cleansing of cobbles by removal of fine sediments would be expected (Table 2.7). Between November 1994 and September 1996, the depth values decreased in both habitat types. In contrast, the percent of surface area embedded showed an inverse pattern, with the November 1994 data having the lowest value and increasing from that date until September 1996. The final substrate characteristic, the D_{50} value, was significantly higher in the riffle habitats (mean values of 3.12 to 3.51 inches (in.)) compared with the runs (mean values 1.56 to 2.73 in.) for all sample periods. No significant differences between seasons were found for runs or riffles (Table 2.7).

Biological parameters were measured to define the primary and secondary biomass within riffles and runs. Periphyton biomass was quantitatively measured on substrates in riffles and runs for the five time periods. These data, expressed as riverwide mean values for each sample period (Table 2.7), indicate a similar pattern between the two habitat types with the riffles having the highest mean value. However, the differences between the two habitat types were not statistically different. Macroinvertebrates, which had about the same amount of organic biomass as periphyton, had similar temporal patterns in riffles and runs. April 1994 had the highest levels of biomass, and November

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Table 2.6. **A comparison of habitat quality features in runs and riffles by geomorphic reach for 1995, 1996, and 1997 combined in the San Juan River.**

	% Embeddedness		D_{50} (mm)		Depth to Embedd. (cm)		Invertebrate Dry Weight (gm/m2)		Detritus (gm/m2)		Periphyton (gm/m2)		Total biomass (gm/m2)	
Date	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**
Riffles														
1	12.0%		62.60		8.00		6.00		34.40		5.00		45.40	
2	12.2%	3.4%	100.12	6.46	10.17	0.91	0.53	0.13	26.36	4.46	1.49	0.40	28.28	4.34
3	20.7%	6.5%	69.91	7.54	8.53	1.17	1.15	0.67	32.98	11.40	3.37	0.82	37.50	11.39
4	10.8%	3.2%	88.77	4.21	11.15	0.85	3.52	1.05	68.03	14.09	3.49	0.95	75.06	14.60
5	10.4%	2.4%	71.77	5.07	8.93	0.61	1.90	0.52	42.94	8.22	3.67	0.49	48.51	8.58
6	24.4%	4.3%	109.52	9.31	9.29	0.94	5.06	1.42	62.74	10.19	6.09	1.56	73.87	11.61
7	29.2%	5.5%	80.05	8.01	7.59	0.83	5.70	1.33	80.75	23.25	3.89	0.59	90.35	23.23
8	7.1%	1.9%	111.38	12.19	11.13	1.04	19.19	8.53	135.68	36.59	3.65	0.61	158.49	40.70
Runs														
1	70.0%		49.80		3.00		0.50				4.30		4.80	
2	45.2%	6.3%	59.58	8.92	7.31	0.88	0.27	0.16	14.09	3.61	1.28	0.34	15.64	3.69
3	53.0%	8.5%	43.25	8.82	3.86	0.65	0.49	0.20	14.16	3.91	2.71	0.40	17.37	4.23
4	55.2%	10.5%	46.58	10.41	4.54	1.21	0.60	0.25	14.85	3.66	3.37	0.68	18.79	3.76
5	36.2%	4.2%	69.31	6.55	5.40	0.61	0.72	0.25	13.89	3.39	3.01	0.47	15.72	3.22
6	50.9%	6.5%	78.54	11.46	4.86	0.69	1.34	0.40	35.13	8.59	4.09	0.62	40.55	8.98
7	52.9%	6.4%	56.65	13.22	7.59	2.44	2.10	0.64	24.13	6.42	3.40	0.75	29.63	6.96
8	28.1%	11.6%	49.81	12.33	5.38	2.00	5.64	1.72	55.17	26.47	3.49	0.56	57.38	23.93

Table 2.7. **A riverwide comparison of habitat quality features for five sample periods in the San Juan River.**

	% Embeddedness		D_{50} (mm)		Depth to Embedd. (cm)		Invertebrate Dry Weight (gm/m2)		Detritus (gm/m2)		Periphyton (gm/m2)		Total biomass (gm/m2)	
Date	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**
Riffles														
Apr 94	26.6%	6.0%	80.86	9.33	5.25	0.52	8.15	2.04	59.05	15.79	7.19	1.12	74.37	17.88
Nov 94	14.1%	4.2%	93.16	6.42	11.59	0.87	1.91	0.48	51.68	12.10	4.54	0.67	58.13	12.72
Apr 95	14.8%	3.2%	77.29	3.80	10.48	0.65	1.93	0.60	30.26	4.04	2.36	0.29	34.46	4.22
Feb 96	14.0%	2.1%	100.33	6.85	10.09	0.53	8.44	3.20	53.61	9.88	2.83	0.37	64.89	12.38
Sep 96	18.4%	4.7%	90.31	7.91	8.73	0.74	1.22	0.40	96.19	20.87	2.39	0.77	99.79	21.40
Runs														
Apr 94	40.3%	7.6%	74.08	12.21	4.31	0.43	2.84	0.63	36.07	8.33	5.62	0.88	33.19	7.97
Nov 94	32.5%	5.7%	57.63	8.43	7.53	0.94	1.55	0.49	28.36	8.22	3.59	0.40	33.48	8.70
Apr 95	44.0%	4.0%	44.03	7.12	6.04	1.87	0.63	0.22	13.13	2.87	2.52	0.31	16.27	2.88
Feb 96	56.3%	6.4%	71.90	7.31	5.91	0.68	2.10	0.78	14.69	3.29	2.97	0.30	19.77	3.69
Sep 96	56.9%	6.8%	49.62	9.43	4.32	0.79	0.26	0.14	29.05	9.04	1.55	0.43	30.87	9.37

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1994 and April 1995 had the lowest levels. In April 1994 and April 1995, riffles had significantly higher invertebrate biomass when compared with run habitats.

Detritus, which represented the largest fraction of organic material sampled in riffle and run habitats, was significantly greater in riffle habitats in three out of five sample periods (April 1995, February 1996, and September 1996). The lowest detrital levels were found in April 1995.
In summary, an analysis of habitat quality in riffles and runs did show some differences between reaches, primarily in biological components in the upper three river reaches (6, 7, and 8). In addition, habitat quality also showed differences among seasons and years.

Comparison with Green and Colorado Rivers

While a full comparison of habitat composition with the Green and Colorado rivers is not possible because of study design differences in the different drainages, some comparisons can be made. Studies in 1990 and 1991 characterized habitat composition in relation to flow for the "15-mile reach" of the Colorado River near Grand Junction, Colorado (Osmundson et al. 1995). The results have been summarized in Table 2.8, showing the percent composition of selected habitat types. Compared with the San Juan River (see Figure 2.7), the 15-mile reach of the Colorado River has a greater abundance of backwater, low velocity, and riffle habitats at all flows. At low flow, backwater habitats constitute almost five times more and other low-velocity habitats three times more of the TWA than in the San Juan River. Even when compared with Reach 1, where backwaters are the most abundant in the San Juan River, backwaters are three times more abundant relative to TWA in the 15-mile reach of the Colorado River. Further, backwater habitat appears to increase with increased flow, counter to the trend in the San Juan River. The responses to flow for the other habitat types in the Grand Valley are similar to the San Juan River.

Table 2.8. Habitat types as a percent of total wetted area (TWA) for the 15-mile reach of the Colorado River at three flow levels.

Flow - cfs	> 7,000	2,000-7,000	<2,000
Backwaters	6.9%	6.6%	4.3%
Other Low-Velocity Types	3.8%	5.3%	6.5%
Runs	78.0%	69.4%	55.2%
Riffles	8.0%	17.7%	23.6%

Source: Osmundson et al. 1995.

Studies by Pucherelli and Clark (1990) and Pucherelli et al. (1990) measured backwaters per river mile in the San Juan and Green rivers. The Green River had three times more backwater habitat than the San Juan River for the areas analyzed. Other characteristics of the San Juan River also were different when compared with the Green and Colorado rivers. The San Juan River exhibited a relatively higher and more-consistent gradient throughout the study reach, resulting in more run and

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riffle habitats than found in the Green or Colorado rivers. Secondary channels and cobble and gravel substrates also appeared to be more prevalent in the San Juan River than in the lower Green and Colorado rivers.